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DIGITAL TERRAIN MODEL IN LEVELLING PLOTTING ON LARGE SCALE TOPOGRAPHIC MAPS

ABSTRACT

Digital terrain model and I_3GTSRP - programme packages to be used in levelling computing and plotting, employing Romanian Felix 256 computer and ARISTO plotter are presented in this paper. Computations take into account two digital terrain model types. INTERCUB-3 programme using bicubic polynomial within a square grid.
Derivate formulae as a matrix product and their numerical values are obtained within computation process, using progressive, regressive and medium difference operator theory. Collocation method engenders a model for random point grids, using INTERCOL programme, which selects trend surface and covariance function automatically.

INTERLIN and GENMATREP programmes compute curve points and test each curve shape matrix. Logical point sorting is carried out by SOL programme, which algorithm is based on curve digitizing in a square diagram. ROT and PLOT programmes bring forth drawing elements. Results obtained are presented as graph, tables and plan section.

1. INTRODUCTION

Digital terrain representation concept has been established during 1955 - 6o at the Massachusetts Institute of Technology (USA) by professor Ch.L.Miller, aiming at optimizing and automatizing way communication designing technologies.

In the course of its twenty five year existence and due to the rapid progress which computation technique has undergone and its impact with the photogrammetric equipment, digital model has been more and more used; its applications to photogrammetry - remote sensing, topography and cartography have become main elements of the present-day technologies used in carrying out complex data banks, rectifying remote sensing data stored on magnetic tapes, automatic map compilation, their updating, orthophoto devices checking, etc.

2. DIGITAL TERRAIN MODEL DEFINITION

Large high speed electronic computers able to store and process large data volume facilitate the object configuration and phenomenon analyses, using analogical methods and equipment, digital object and phenomenon image carrying out into computer storage,based on data obtained after measurements in discrete points. Analytical Stereoplotter coming into existence and minicomputer and automatic data recording system - assisted analogical plotters allowed the digital terrain representation (and other planet representations) photogrammetrically.

Various studies, experiments and applications related to digital model emphasize its present-day evolution,presenting it as a complex system able to contain and analyse different terrestrial crust features. Former primary stage vector, comprising X,Y,Z coordinates, now,enlarges its size containing other data types: geology, hydrology, soil science, gradients,terrain values and uses, etc.; thus, digital terrain model can be used to show a general system,containing digital relief model , as well.

So,digital terrain model can be defined as a system composed of a ordered set of vectors, which elements stored in computer memory are the space comprehensive distribution of terrain features and computing programmes based on mathematical models, able to establish various terrain features precisely in points which planimetric position is known.

Technological structure of the digital model is made up of the following basic elements: information collection (sampling), equipment,information processing, their storage,structure and applications.

3. I_3GTSRP PROGRAMMES USED IN AUTOMATIC LEVELLING COMPUTATION AND LOCATION

Considering advantages devided from digital model technologies and computing technique, programmes to compute and locate levelling on large scale topographic maps automatically, in relative flat surface zones have been achieved. Romanian C - 256 Felix computer is used to process photogrammetric information and ARISTO plotter is used to compile maps automatically.

Programmes are derived as against the following logical diagram:

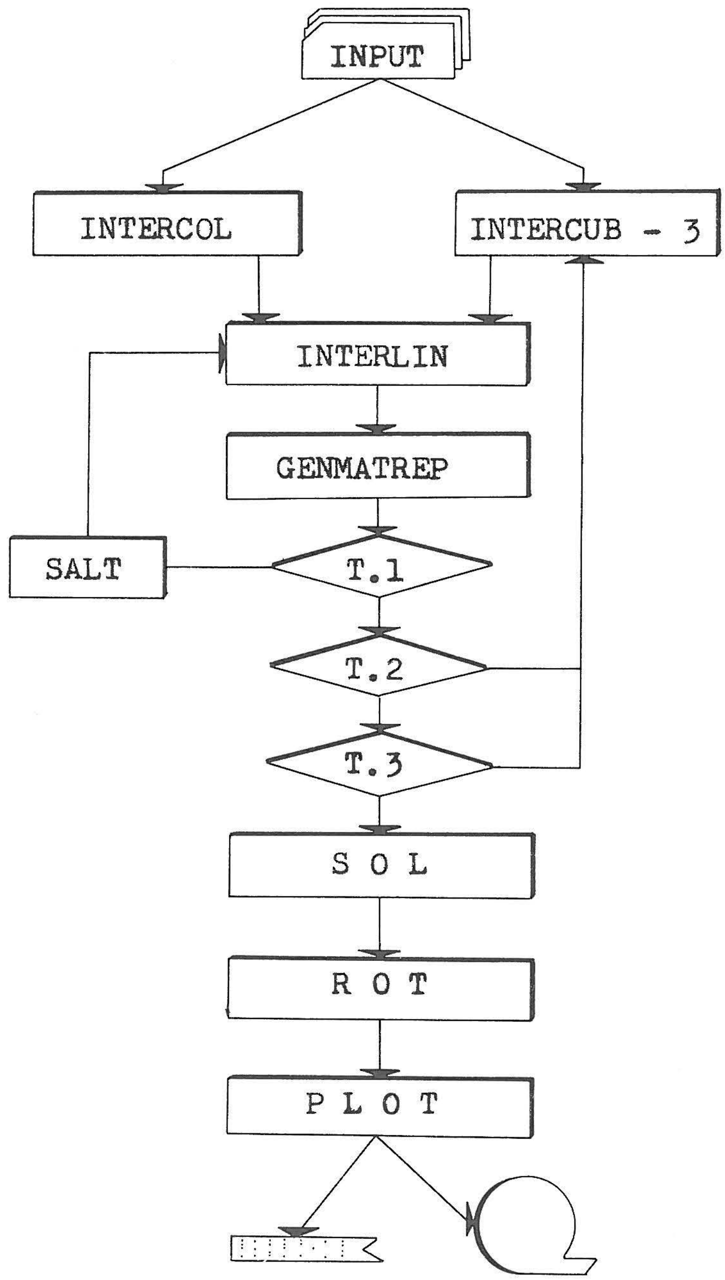


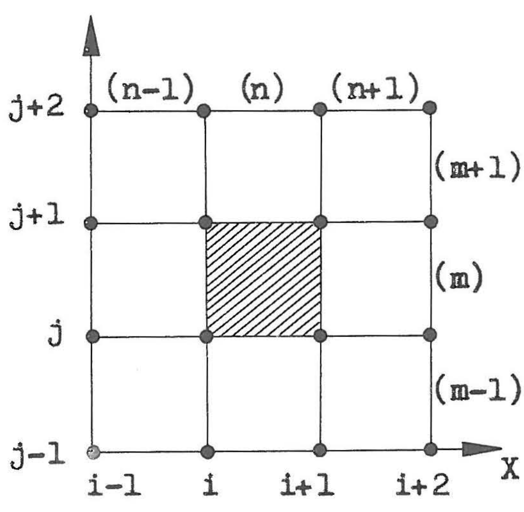
Figure 1. I_3GTSRP programme logical diagram

Input data measurements are carried out partial automatically, using A8 Wild Autograph assisted by EK-5 automatic recording device. Sampling is made using a square network, which step (h) is established employing transfer function or measuring points, which the operator has selected after terrain photo-interpretation on a stereomodel.

Data processing (previously tested and partitioned in computation units) begins with carrying out digital height terrain model, using INTERCUB - 3 programme, if reference point network is uniform and its algorithm is determined using polinomial interpolation method, element - by-element, employing a complete bicubic polynom:

$$Z = f(x,y) = X\ A\ Y^T \qquad (1)$$

The sixteen parameters of the polynom are established giving four conditions in corner points of each network element (Figure 2).



$$\begin{aligned} 1.\ & \left[Z^{m,n}\right]_{ij} = \left[Z^{m,n-1}\right]_{ij} \\ 2.\ & \left[Z_x^{m,n}\right]_{ij} = \left[Z_x^{m,n-1}\right]_{ij} \\ 3.\ & \left[Z_y^{m,n}\right]_{ij} = \left[Z_y^{m,n-1}\right]_{ij} \\ 4.\ & \left[Z_{xy}^{m,n}\right]_{ij} = \left[Z_{xy}^{m,n-1}\right]_{ij} \end{aligned} \qquad (2)$$

Figure 2.

Numerical value of three derivates, using (Z) measured heigts are computed in all network points. First-order derivates (Z_x and Z_y) in x and y directions, respectively, ensure modelling surface continuity and mixed derivate (Z xy) ensures **smoothness.** Polynom derivate expressions are obtained automatically, using a computer as matrix product:

$$Z'_x = X'A\ Y^T \ ; \ Z'_y = X\ A\ Y'^T \ ; \ Z''_{xy} = X'A\ Y'^T \qquad (3)$$

Then, their numerical values are established, using subrou - tines employing computation formula of the difference operator theory.

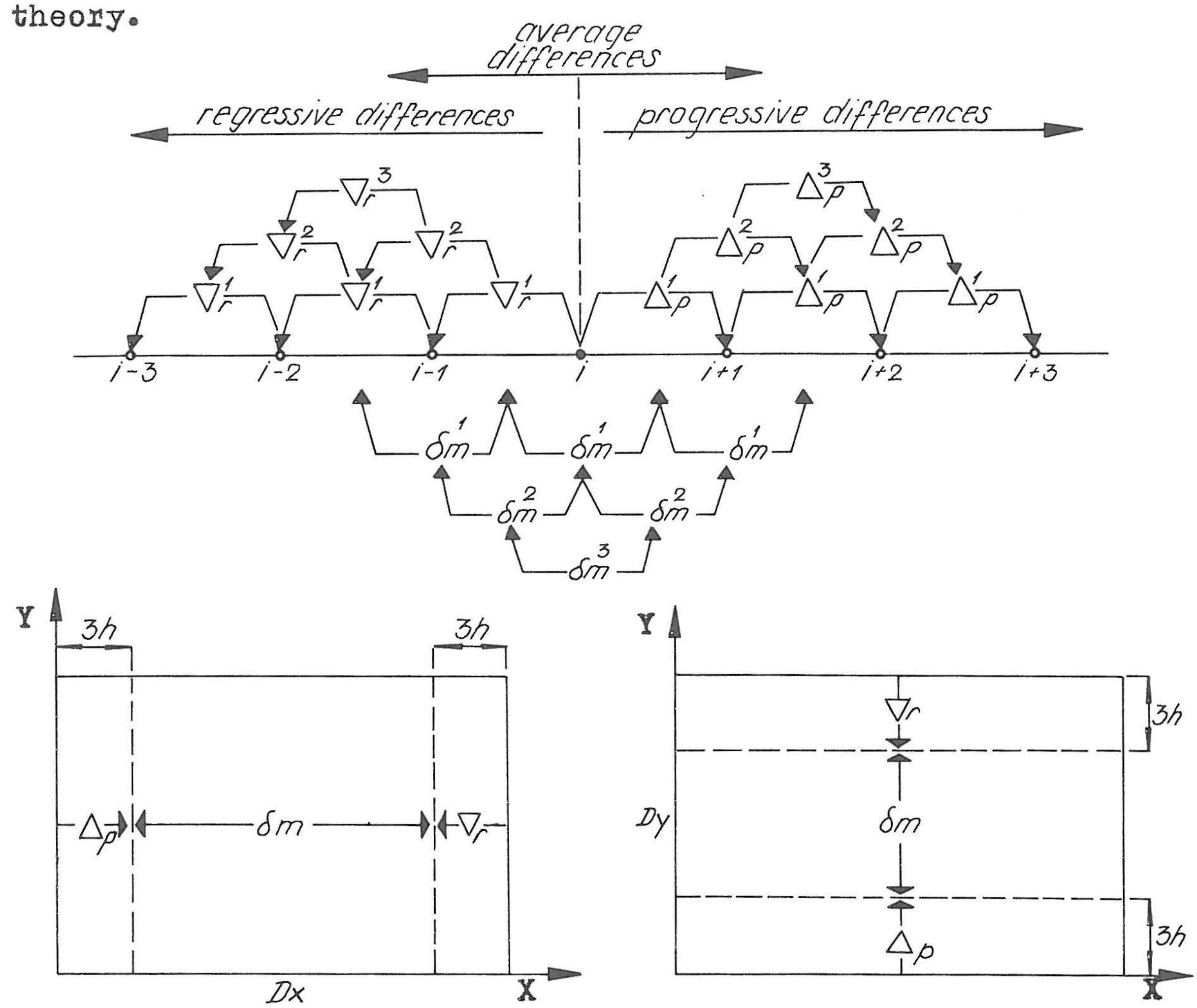


Figure 3.a) Computation diagram for differences and b) computation unit partitioning to establish derivate numerical values

Subroutines are built for progressive, regressive and average difference operators, according to formula (4) and Figure 3.

$$Z'_{x(y)} = \frac{1}{h}\left(\Delta^1_p - \frac{\Delta^2_p}{2} + \frac{\Delta^3_p}{3} + \cdots\right); \quad Z''_{xy} = \frac{1}{h^2}\left[\Delta x\Delta y - \frac{1}{2}\left(\Delta x\Delta^2 y + \Delta^2 x\Delta y\right) + \cdots\right]$$

$$Z'_{x(y)} = \frac{1}{h}\left(\nabla^1_r + \frac{\nabla^2_r}{2} + \frac{\nabla^3_r}{3} + \cdots\right); \quad Z''_{xy} = \frac{1}{h^2}\left[\nabla x\nabla y - \frac{1}{2}\left(\nabla x\nabla^2 y + \nabla^2 x\nabla y\right) + \cdots\right] \quad (4)$$

$$Z'_{x(y)} = \frac{1}{h}\left(\delta^1_m - \frac{1}{6}\,\delta^3_m + \cdots\right); \quad Z''_{xy} = \frac{\mu x\,\mu y}{h^2}\left[\delta x\delta y - \frac{1}{6}\left(\delta x\delta^3 y + \delta^3 x\delta y\right) + \cdots\right]$$

Difference operator uses ensure programme flexibility and high height accuracy for new interpolated points, owing to rigorous numerical values of derivates and complete plotting of mea - sured point network, having the possibility to interpolate points in squares in the computation unit limits, as well.

Equation system for polynom coefficient establishments has the following shape:

$$\begin{bmatrix} Z \\ Z'_x \\ Z'_y \\ Z''_{xy} \end{bmatrix} = \begin{bmatrix} X & X' & X & X' \end{bmatrix} \cdot \begin{bmatrix} A & 0 & 0 & 0 \\ 0 & A & 0 & 0 \\ 0 & 0 & A & 0 \\ 0 & 0 & 0 & A \end{bmatrix} \cdot \begin{bmatrix} Y \\ Y \\ Y' \\ Y' \end{bmatrix} \qquad (5)$$

Having a square reference point network, coordinate system origin is located into the interpolated point, thus reducing the computation time to a large extent. So, coefficient matrix of K equations is computed and inversed once, considering programme starting; succesive system resolutions by free term changes corresponding to each square in the network is, then, carried out:

$$A_{i,j} = K^{-1} L_{i,j} \qquad (6)$$

Z height of the interpolated point being equivalent to A_{oo} term. Processed computation units can range from 25 to 1000 points.

If reference point network is sampled by selecting points , when the operator makes the relief photointerpretation, digital model formation is provided by INTERCOL programme, which is based on interpolation principle using colocation method.

$$Z = T(x,y) + c^T C^{-1} L \qquad (7)$$

Tendency surface selection is made automatically, depending on the reference points to be found within the established field for each new computed point interpolation, thus, surface being defined by an incomplete two-or three - degree polynom.

Gauss curve equation selected as against the ground type(relative flat presenting moderate undulating shapes) is used as covariance function during the interpolation process. In the first stage, interpolation is carried out without filtering, considering $C(o) \neq V$ ($C(o)$ is established depending on d min) and the obtained evaluation precision is tested, using the following expression:

$$m = C(o) - c^T C^{-1} c \leq m_{adm}. \qquad (8)$$

If assumed error value is exceeded, computation is repeated using filtering, considering: $C(o) = (1 - 10^{-4})\,V$.

Computation units for INTERCOL programme contain from 100 to 1000 points and the processing result is a model having a square network shape.

After digital height model is obtained using one of the two above mentioned programmes, points are stored in files on magnetic tapes, containing ($Z_{i,j}$) coordinates, (h) step value, (X_o, Y_o) origin and (i, j) network dimensions only; $X_{i,j}$, $Y_{i,j}$ coordinates being inferred during subsequent processings, using computation formula: $X = X_o + ih$ and $Y = Y_o + jh$.

File information are input data for INTERLIN linear interpolation programme used to compute maximum height, minimum height, contour lines, their values and points located on contour lines on each side of the squares making network, corresponding to contour interval introduced as initial parameter.

New points computed, using linear interpolation, are sorted as vectors considering contour line values and, then, they are introduced into files on magnetic tapes.

INTERLIN programme results are further processed by GENMATREP programme, which establish matrix to represent each contour line. Matrix elements are contour line intersections with each square side of the network, their value ranging from 0 to 4. After the matrix has been established, contour line configuration is tested (Figure 1, T1, T2, T3 tests) comparing all matrix lines, columns and diagonals to detect zones with very winding contour lines (T2, T3 tests), as for exemple:

3	3	2
2	3	2
2	2	0

;

0	2	2
2	4	2
2	2	0

;

2	0	2
3	2	3
2	2	2

etc.

as well as curve points identical with network points(T1 test). Cases when contour line intersects all square sides or has many windings in the other squares are eliminated by digital model network bridging, using INTERCUB - 3 programme. Cases when model network points are identical with contour line points are eliminated, using SALT subroutine, which translates reference plane vertically with 5 per cent of the contour interval. INTERLIN and GENMATREP programme computation sequences are further repeated, corresponding to diagram in Figure 1, considering both cases.

After all contour lines fulfill conditions imposed by T1, T2, T3 tests, vectors containing sorted points, taking into account each curve value, are introduced into file on tapes and they are further processed, using SOL logical sorting programme, based on digitizing curves in a square net. Programme has a modular structure consisting of subroutines to analyse the most probable curve shapes, considering 36 cases used to solve all possibilities existing on the ground. Curves existings into a computational unit were divided into two categories: closed curves and open curves considering this classification, the correct shape of each curve is established by logical point sortings after each square of the network containing the curve has been investigated,without generalizing curve shape.In case of open curves,the work starts from the beginning points (points being continuous in the adjacent unit);in case of closed curves, the work starts from the first point identified on the respective curve.

Points which SOL programme has sorted represent contour line as a polygon. Polygonal shape is rounded,thus,curve acquires its usual shape after ROT programme processing;in this way,10 or 20 points are derived on each side as against side lenght, using sliding interpolation method and polynoms having the following form:

$$P(x) = a_0+a_1x+a_2x^2+a_3x^3+a_4x^4+a_5x^5 \qquad (9)$$
$$P(y) = b_0+b_1y+b_2y^2+b_3y^3+b_4y^4+b_5y^5$$

First - and second - order derivate continuities are required, in order to obtain a smooth and continuous connection of various curve parts. So-obtained points represent the usual contour line shape and they are processed as input data in PLOT automatic drawing programme in ARISTO plotter, which provides the final contour line plottings, drawing it on various paper holders or engraving it on plastic foils covered by engraving layer. Two plane sections obtained, using I_3GTSRP programme in data processing, are presented in Figure 4.

4. CONCLUSIONS

Tests and experiments provided by I_3GTSRP programme have shown that contour lines can be obtained digitally, presenting proper precision and cartographic quality required by levelling representation on large scale topographic maps. As compared to usual analogic plotting, using computation and automatic levelling plotting is more precise, especially on flat surfaces. As it is well-known, stereoplotting operator cannot plot contour line precisely on flat surface, because its small gradient.

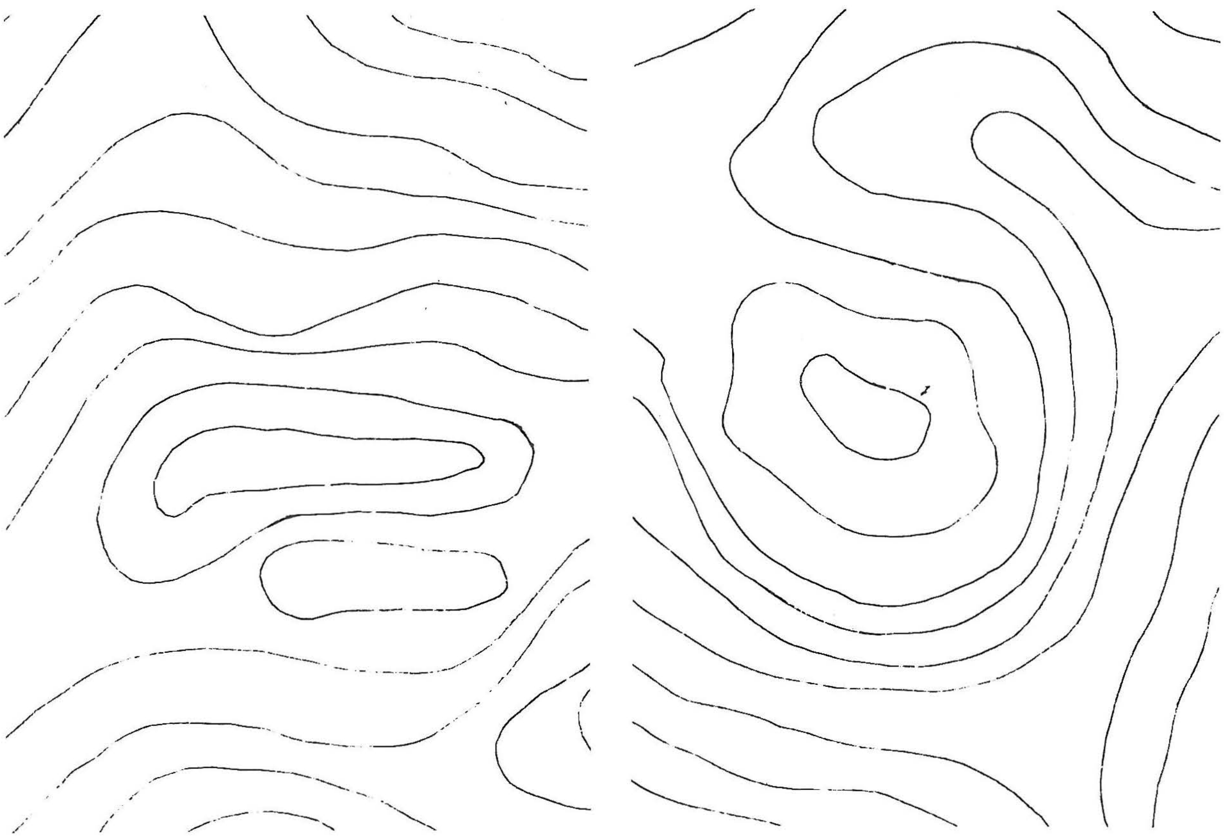


Figure 4. 1:5,000 scale topographic map sections obtained by digital plotting, using I_3GTSRP programme

Data sampling is a basic parameter in analitical levelling plotting. Results established by quality and precision stan - dards can be obtained only by overlaping surface to be plotted with a measured point network, which number and density should represent terrain variations and morphological features rigo-rously and properly. So, we must say that information lost du-ring sampling process could not be refind by a high complex degree interpolation method. As regards information collection, progressive sampling is a proper method, but it requires an assisted computer-equipment; thus, off-line processing variant is too expensive.

Transfer function, considering the smallest detail to be plot-ted in order to establish point network step, ensures an over-lapping sampling; in this way, not only a high plotting accu-racy is obtained but also data redundancy, which entails a cost increase as a result of a larger sampling time.

Automatic levelling plotting increases work proficiency, ensu-ring high quality and low cost products.

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